The Next Wave? Emerging Technologies in Desalination and Water Treatment

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Topics Overview

- Osmosis technologies
  - Osmosis
  - Membranes
- Current desalination
  - Reverse osmosis
- Research being pursued
  - Forward osmosis
- Other technologies

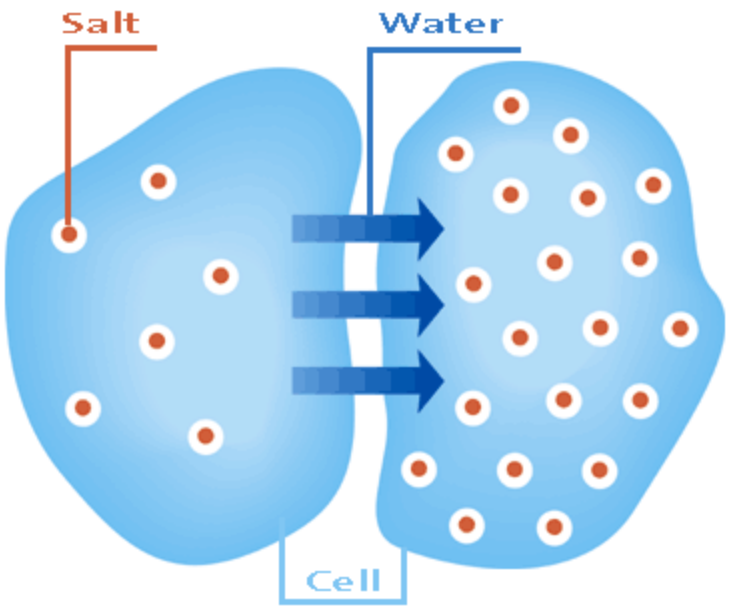
Literature Review*

***This presentation relied heavily on the research and publications of others:**

- Research articles and publications are referenced at the end

Osmosis

- Natural phenomenon
  - Living cells
- Osmosis is the spontaneous movement of solvent molecules through a selectively-permeable membrane into a region of higher solute concentration, aiming to equalize the solute concentrations on the two sides.



Osmosis Technologies

- Reverse osmosis (RO)
  - Water purification and other applications
- Forward or direct osmosis (FO)
  - Niche applications and research
- Pressure-retarded osmosis (PRO)
  - Energy generation and research

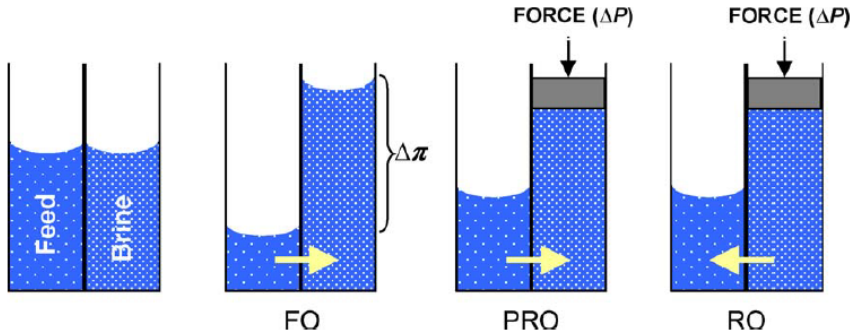
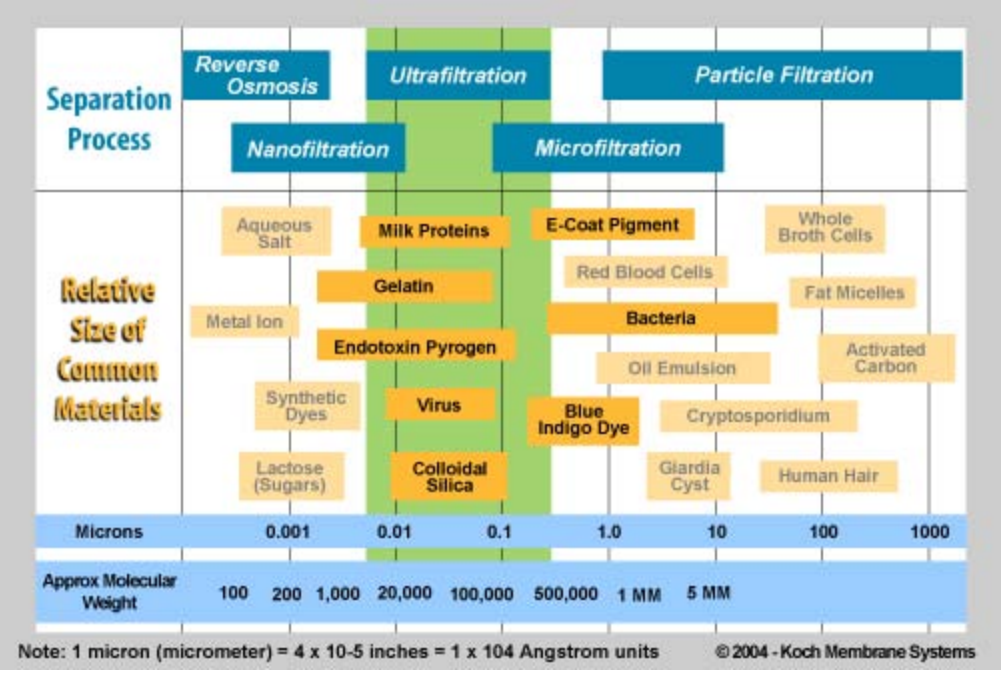


Fig. 1. Solvent flows in FO, PRO, and RO. For FO, ΔP is approximately zero and water diffuses to the more saline side of the membrane. For PRO, water diffuses to the more saline liquid that is under positive pressure ($\Delta\pi > \Delta P$). For RO, water diffuses to the less saline side due to hydraulic pressure ($\Delta P > \Delta\pi$).

Source: Cath et al., 2006

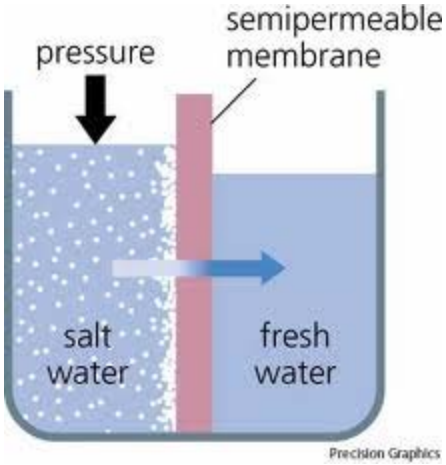
Membranes

- Pore size
  - Microfiltration (~0.1 μm)
  - Ultrafiltration (~0.01 μm)
  - Nanofiltration (~0.001 μm)
  - Reverse osmosis (~0.0001 μm)
- Construction
  - Flat plate and frame
  - Spiral wound
  - Tubular
  - Hollow fiber
  - Others



Desalination - Overview

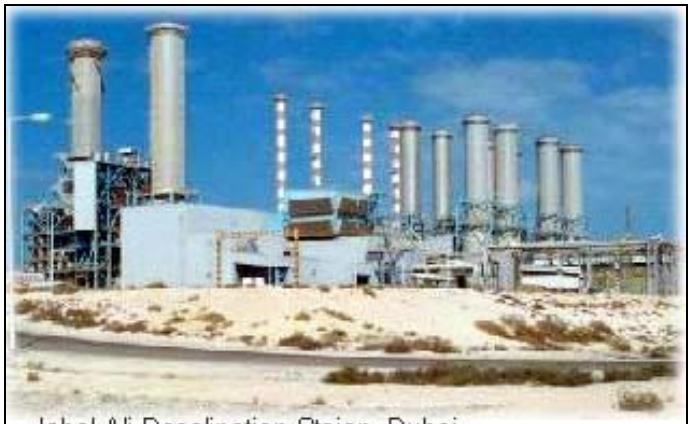
- Group of processes used to produce fresh water from brackish water or seawater for a variety of uses
- Reverse osmosis is leading technology
- Primarily thermal or membrane technologies
  - Thermal:
    - Multi-stage flash (MSF)
    - Multi-effect evaporation (MEE)
  - Membrane:
    - RO
    - Electrodialysis



Reverse osmosis

Desalination – Where applied

- Not much activity in the Northwest, due to our relatively plentiful water supplies
  - Many countries in Middle East rely in desalinated seawater for a key portion of their water supply.
  - In the U.S., plants have been developed primarily in California and Florida.
- Could change with future water demand or potential impacts of climate change



Jebel Ali Desalination Staion, Dubai
Lahmeyer International

Desalination Plant in Jubail II Industrial Zone, Saudi Arabia.

Desalination – Energy use

- High energy use
  - Heat for evaporative technologies, electricity for pressurized membrane applications
  - Several coastal applications report energy use ranging from 13 – 23 kWh/1,000 gallons
    - Another survey suggests 11 – 30 kWh/1,000 gallons
    - Theoretical minimum as low as 3 kWh/1,000 gallons
  - Commonly applied only in areas with serious water supply challenges, plentiful cheap energy, or both

Desalination – Pros and cons

Pros:

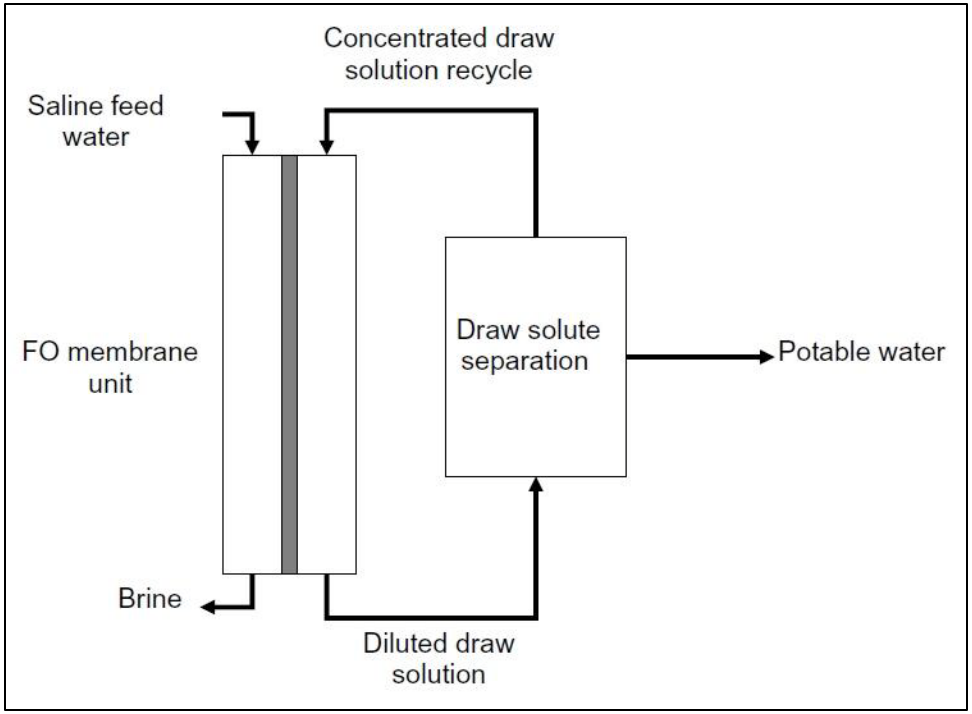
- Seawater or brackish sources – not competing with other water users for freshwater sources
- High purity product water
- Emerging contaminants
- Potential for combining with renewable energy sources
- Relatively few consumables

Cons:

- Intake challenges – potential harm to marine life
- Pretreatment
- Post-treatment
- Membrane fouling
- Scaling
- Concentrate waste stream disposal – especially inland

Forward osmosis

- How is it different?
  - Driving force is an osmotic pressure gradient
  - High concentration draw solution to induce water flux across semi-permeable membrane
  - Draw then separate



Source: McCutcheon et al., 2005

Forward osmosis

- Types of draw solutions proposed for different applications (remove easily and entirely):
  - Ammonia-carbon dioxide
  - Brine or seawater
  - Sulfur dioxide
  - Aluminum sulfate
  - Glucose/fructose
  - Potassium nitrate
  - Magnetic solutes
  - Others

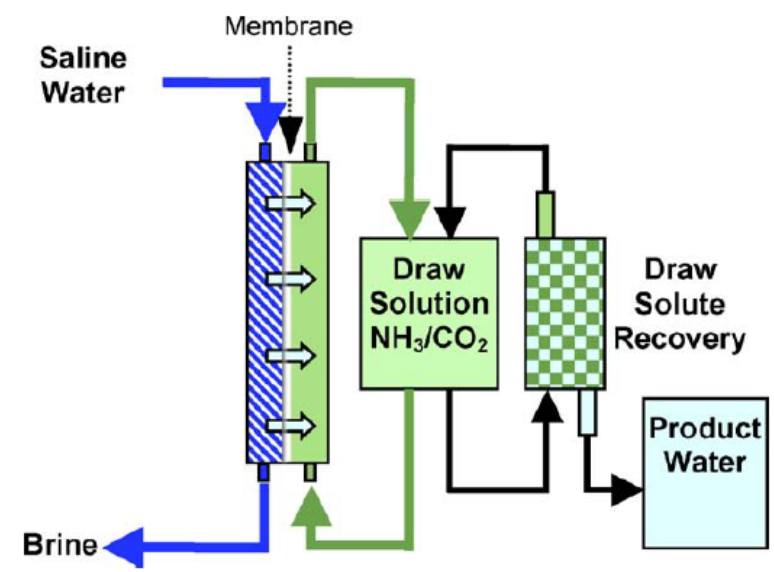


Fig. 16. Schematic drawing of the novel ammonia–carbon dioxide FO process [22].

Source: Cath et al., 2006.

Forward osmosis – Other applications

- List of non-water treatment applications from research
  - Wastewater treatment
  - Concentration of industrial or landfill waste streams
  - Space life-support systems
  - Food and pharmaceutical production
- Hydration Technology Innovations (HTI)
  - Manufacturer of FO membranes
  - List a variety of niche applications, including personal hydration bags for survival or outdoors use

Forward osmosis – Cost and energy benefits

- Research publications
  - Heat to 60°C to recover solutes from diluted concentrate; possible with lower grade waste heat
  - Possible energy savings of 72-85% over current desalination technologies.
- Oasys
  - As little as 1/10 the energy input of RO
  - Heat to 40-50°C, versus 70-100°C for other thermal processes
  - Lower capital cost for low-pressure system
- QuantumSphere
  - "The forward-osmosis process we've developed can purify water at less than 3,000 kWh per acre foot (2.43 kWh/m^3), which is approximately 70% cheaper than the energy cost of traditional reverse-osmosis processes."

Forward osmosis – Other considerations

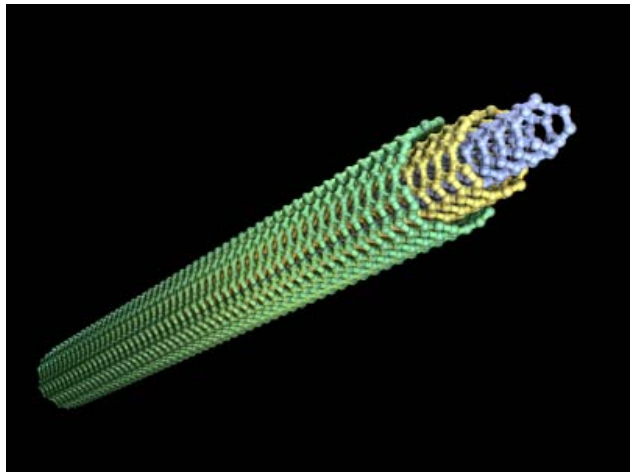
- Lower membrane fouling potential?
- May have decreased capital costs due to low-pressure construction
- May be favorable application where waste heat is available from power or industrial processes
- Best suited for coastal applications with brackish or seawater sources

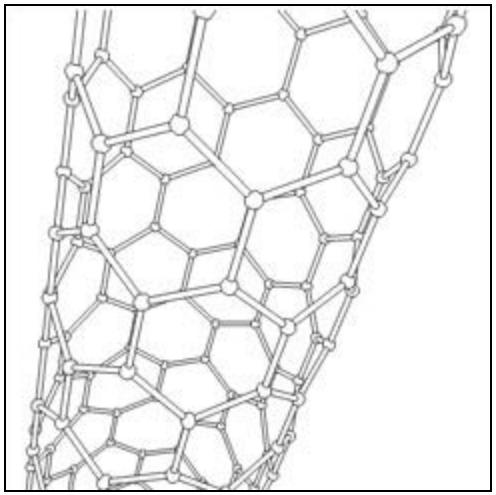
Forward osmosis – Hurdles

- Concentration polarization (CP)
  - Surface phenomena reduces water flux across membrane well below theoretical values
  - Internal/external and concentrative/dilutive
- Improvements needed to membranes for FO
  - Membranes specific to FO, limit surface loss phenomena
  - Salt diffusion across membranes a challenge in some applications
- Like RO, may require auxiliary equipment for pretreatment, post-treatment, or brine disposal.
  - Adds to capital and operating costs

Other Technologies

- Carbon nanotube enhanced filtration
  - Use carbon nanotubes imbedded in traditional membranes to enhance desalination characteristics
  - Or, carbon nanotube membranes to replace traditional membrane materials
- Carbon nanotube adsorption
  - Use carbon nanotubes as an adsorption media to remove a variety of water constituents
- Other engineered nanomaterials or agents





ETA?

- A question of if <u>and</u> when
  - Can the technologies advance sufficiently to be cost effective?
  - Simplicity of treatment trains, practical energy use will be considerations
  - Technological hurdles to be overcome
  - Keeping up with incremental RO advances
- The right alignment of factors for an application
- Related technologies may provide opportunities to treat contaminated or low quality sources of water

References

- List of reference articles

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Questions?

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